Discovery of one-dimensional topological insulator for qubits, other technology

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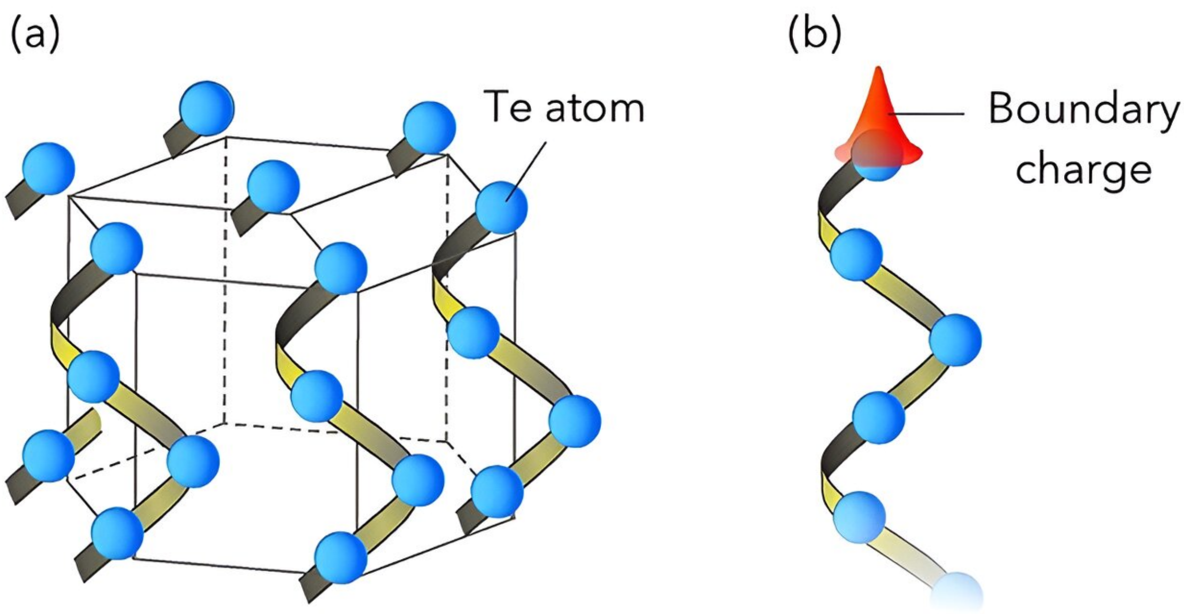


(a) Schematic of Te crystal which is formed by hexagonal arrangement of Te helix chains. (b) Single Te helix chain with boundary charge. Credit: Tohoku University

A joint research team that included members from Tohoku University has unveiled a new topological insulator (TI), a unique state of matter that differs from conventional metals, insulators, and semiconductors.

Unlike most known TIs, which are either three- or two-dimensional, this TI is one-dimensional. The breakthrough will lead to further developments of qubits and highly efficient solar cells.

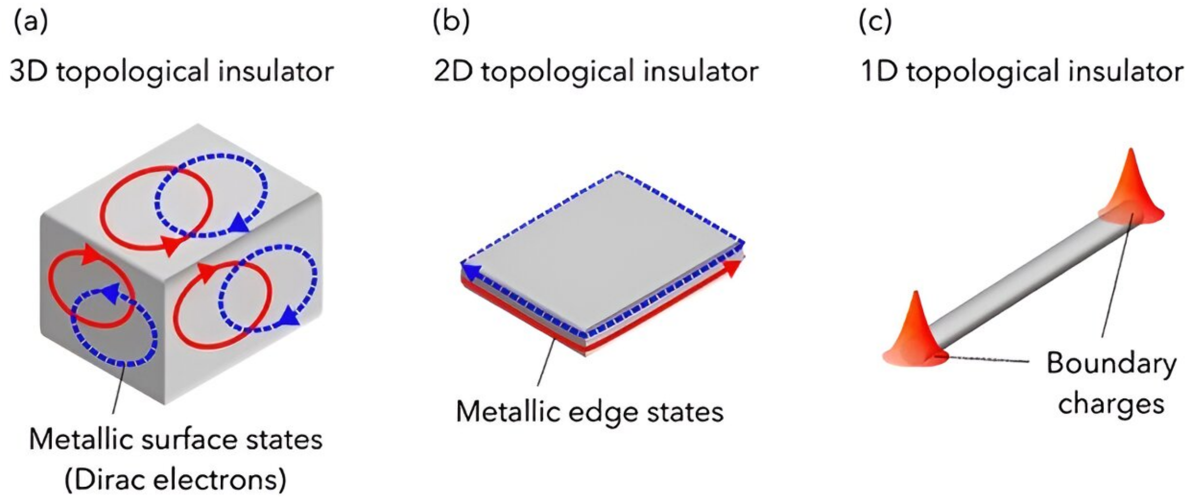
Details of the research were published in the journal *Nature* on June 6, 2024.

TIs boast an interior that behaves as an electrical insulator, meaning electrons cannot easily move; whereas its surface acts as an electrical conductor, with the electrons able to move along the surface.

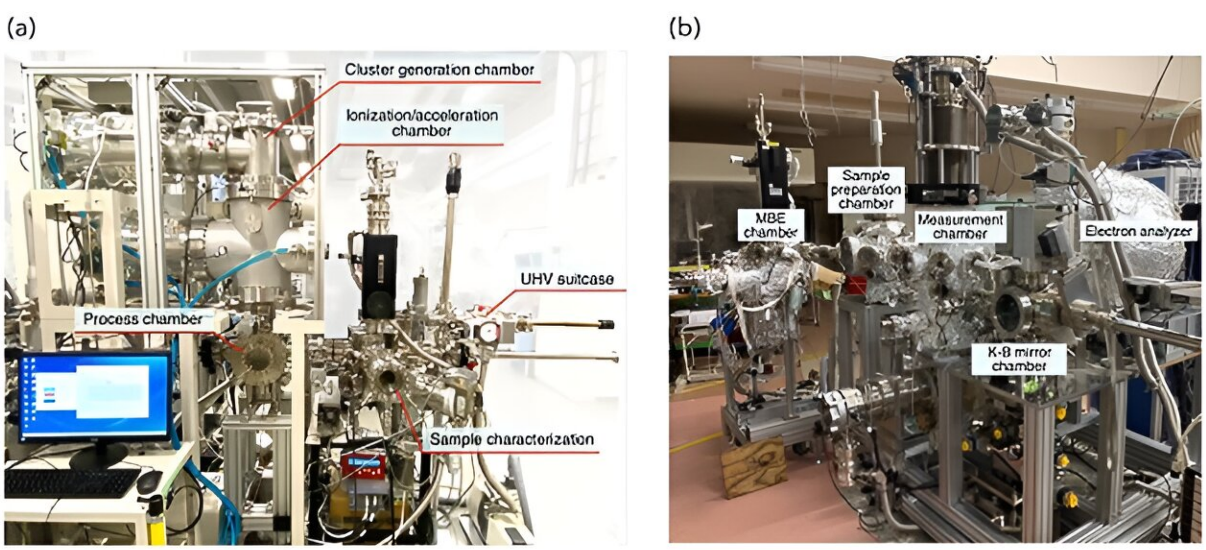
Ever since three-dimensional TIs were reported on in the 2000s, researchers have been on the hunt for new ones. Yet one-dimensional TIs have remained largely elusive.

"One-dimensional TIs are particularly intriguing because the electric charges that appear on their end points effectively constitute qubits—the basic unit of information in quantum computing. And hence vitally important to quantum physics," points out Kosuke Nakayama, an assistant professor at Tohoku University's Graduate School of Science and co-author of the study.

Nakayama and his colleagues focused their attention on tellurium (Te), a semiconductor whose primary commercial use is in solar panels and thermoelectric devices. Recent theoretical predictions have suggested that single helix chains could in fact be one-dimensional TIs. To verify this, the team needed to observe the electrical charges confined to the endpoints of these chains.



Schematics of (a) three-dimensional, (b) two-dimensional, and (c) one-dimensional topological insulators. Credit: Tohoku University



Photographs of (a) the gas cluster ion beam (GCIB) system constructed at Tohoku University and the angle-resolved photoemission spectroscopy (ARPES) system with micro-focused optics at Photon Factory, KEK. Credit: Tohoku University

This required preparing clean edges of the Te chains without structural damage, something made possible by employing a newly developed gas-cluster ion-beam (GCIB) system, which can modify surfaces to within a nanometer.

They then visualized the spatial distribution of electric charges using an angle-resolved photoemission spectroscopy (ARPES) with a micro-focused beam. Their investigations confirmed that the electric charges did indeed appear at the endpoints of the chains, thus supporting the one-dimensional TI nature of Te.

Nakayama stressed that their research marks a crucial step toward understanding the properties of one-dimensional TIs and will have wide-ranging benefits. "The charges at the endpoints of one-dimensional TIs have a variety of uses: qubits, high-efficiency solar cells, high-sensitivity photodetectors, and nanotransistors.

"Our discovery of a one-dimensional TI will help accelerate research towards the realization of these applications."

More information: K. Nakayama et al, Observation of edge states derived from topological helix chains, *Nature* (2024). DOI: 10.1038/s41586-024-07484-z

Provided by Tohoku University

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